

Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

Session Title

Pre and Post Combustion CO₂ Capture Strategies Using Membranes

Richard A. Callahan
Enerfex, Inc.

Kevin C. O'Brien
SRI Consulting

Robert R. Dill
Specialty Filaments, Inc.

May 8-11, 2006 • Hilton Alexandria Mark Center • Alexandria, Virginia

Post Combustion Membrane Capture

- Existing & future pulverized coal plant flue gas
- Membranes selectively permeate CO_2 , NO_x & SO_x & retain N_2
- Economics driven by permeability & selectivity
- Higher permeability lowers membrane capital
- Higher selectivity lowers capture power

Enerfex, Inc.

- Company Formed 1992
- Membrane Project Areas:
 - Design – Process simulation
 - Plant & Pilot Skid – Design & Fabrication
 - Natural Gas – Well Head CO₂ removal
 - Fuel Cells – Natural gas N₂ content reduction
 - DOE – Industrial NH₃ refrigerant membrane
 - NASA – Mars atmosphere utilization membrane
- Several U.S. & foreign patents issued & pending



Fuel Cell N₂ Reduction Membrane Separation Unit (MSU) to prevent electrolyte NH₃ poisoning

SRI International

Independent R&D organization known for commercialization of new technologies



SRI headquarters, Menlo



Sarnoff Corporation,
Princeton, NJ

- Sarnoff India
- SRI Taiwan

- Founded by Stanford University in 1946
 - A nonprofit corporation
 - Independent in 1970; changed name from Stanford Research Institute to SRI International in 1977
- Sarnoff Corporation acquired in 1987
 - 2,000 staff members combined
 - 800 with advanced degrees
 - More than 15 offices worldwide
- Consolidated 2005 revenue: \$390 million
- Multidisciplinary teams formed to commercialize technologies



SRI – State College, PA



SRI – Tokyo, Japan



SRI – Washington, D.C.

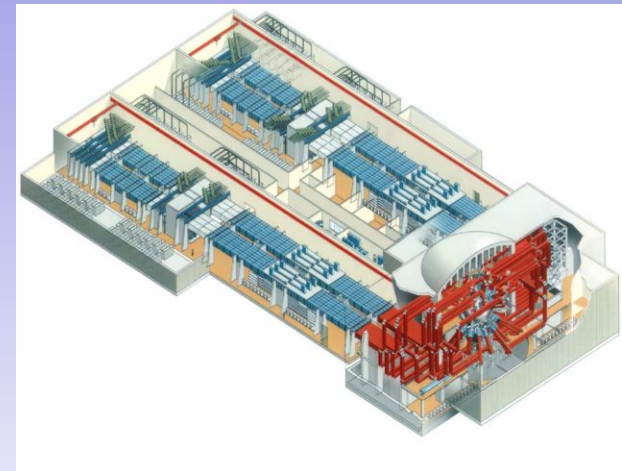


Lawrence Livermore National Laboratory

Managed by the University of California for the Department of Energy



| | |
|--|---------------------|
| Employees | Capital Plant: \$4B |
| LLNL: | 7,250 |
| Other: | 750 |
| Annual Operating and Capital funds: ~\$1.6B/yr | |



Site for National Ignition Facility (NIF)

LLNL Mission:
Ensuring national security and applying science and technology to the important problems of our time

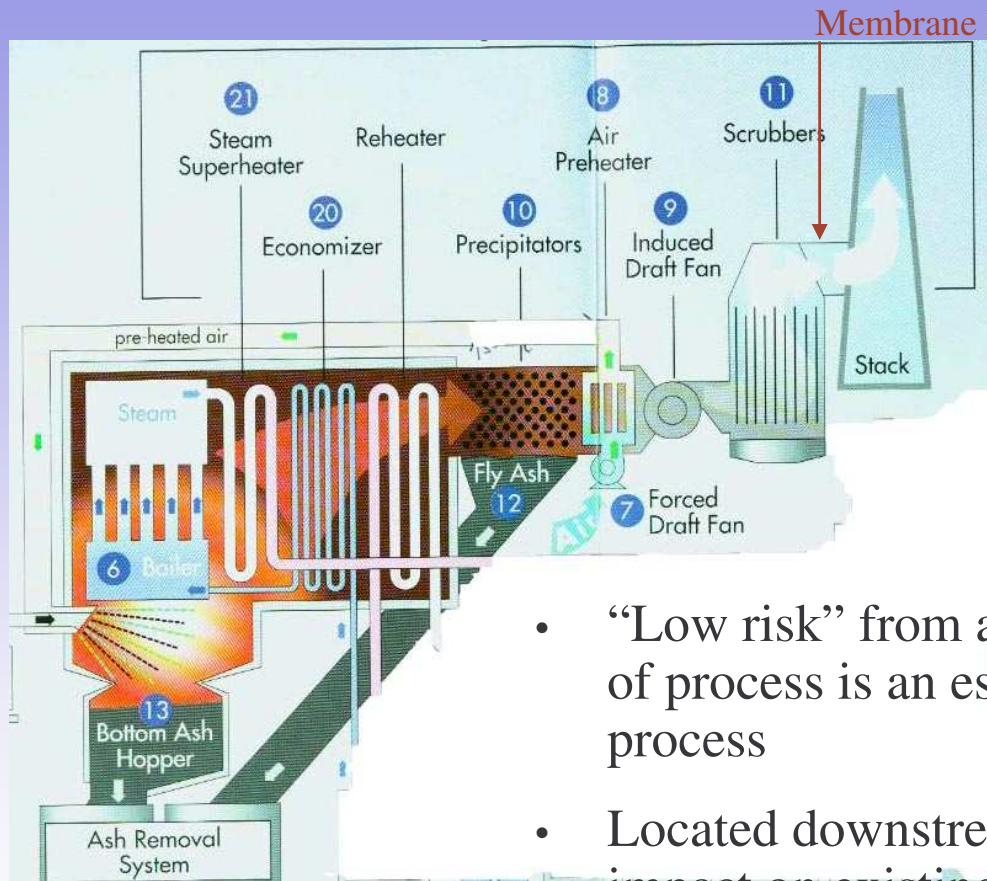
Specialty Filaments, Inc.



- Operating since 1873
- Have produced hollow fibers since 1970
- Several US and Foreign patents covering hollow fibers

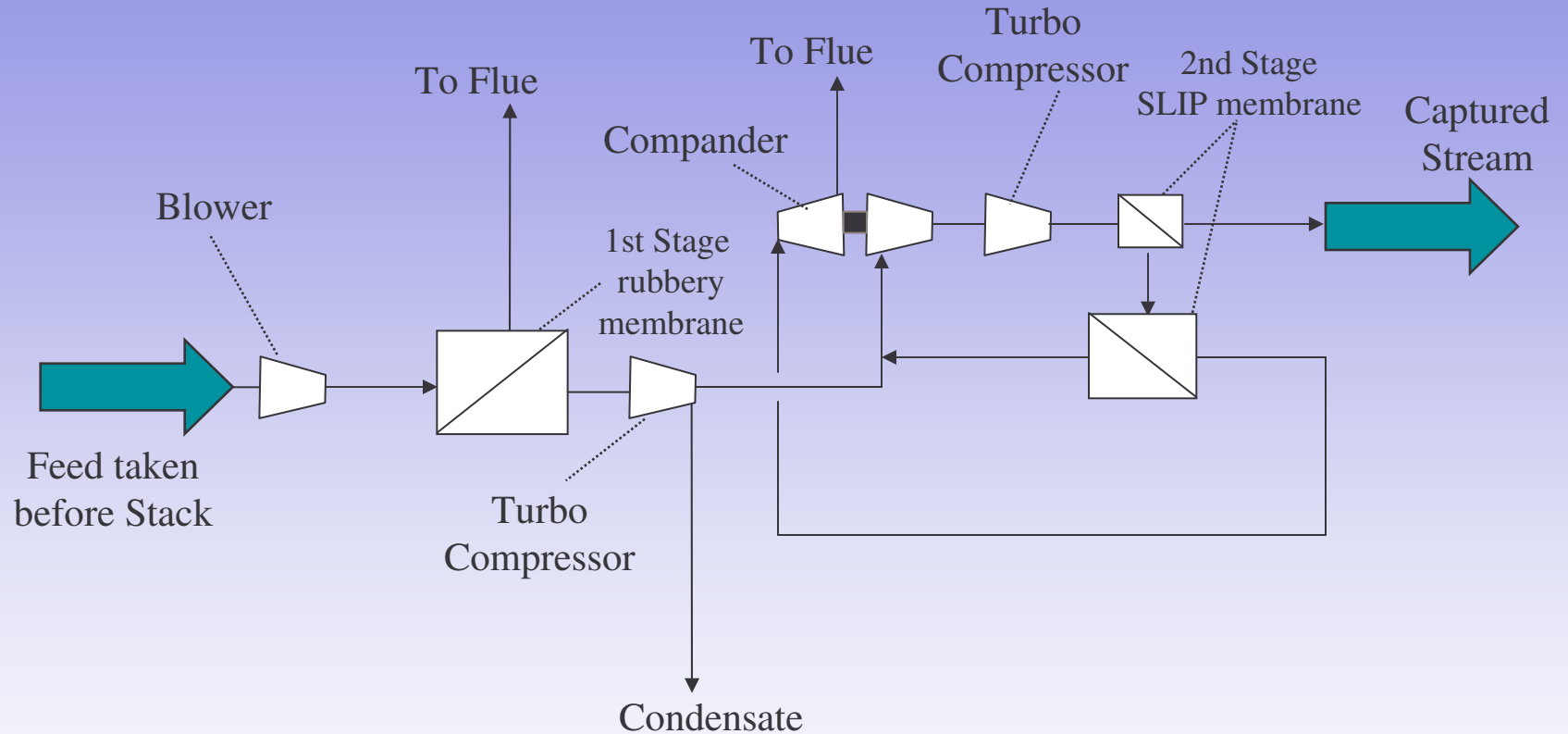


POST Combustion Capture At EXISTING Power Plants Creates A Near Term Opportunity



- Peak Power output available by bypassing capture system during peak demand
- Does NOT create additional “consumables” or require waste disposal
- “Low risk” from an engineering perspective, i.e. basis of process is an established industrial separation process
- Located downstream from existing process with little impact on existing process
- Power Plant suggests locating MSU between scrubber & stack
- Stack Gas Temperatures of 125-135°F (50-60°C)

Post Combustion System Design



- Enerfex, Inc. patented MSU system is the most economic approach
- First Stage: High permeability and high recovery MSU
- Second Stage: High selectivity and High Purity MSU

Existing Plant Identified as Potential Location for Post Combustion Capture System

- Proposed demonstration site would be coal-fired Navajo Generating Station or Coronado Plant near Navajo Nation
- System located between scrubber & stack based on discussions with plant engineers



Stack & Scrubber At Navajo
Generating Station

Pathway to Pilot Scale Test at Power Plant



*Integrate Turbo
Compressor with
Skid and Produce
SLIP coated Fiber*

Year 1



*Fabricate SLIP
Membrane Module,
integrate into skid and
evaluate in controlled
setting*

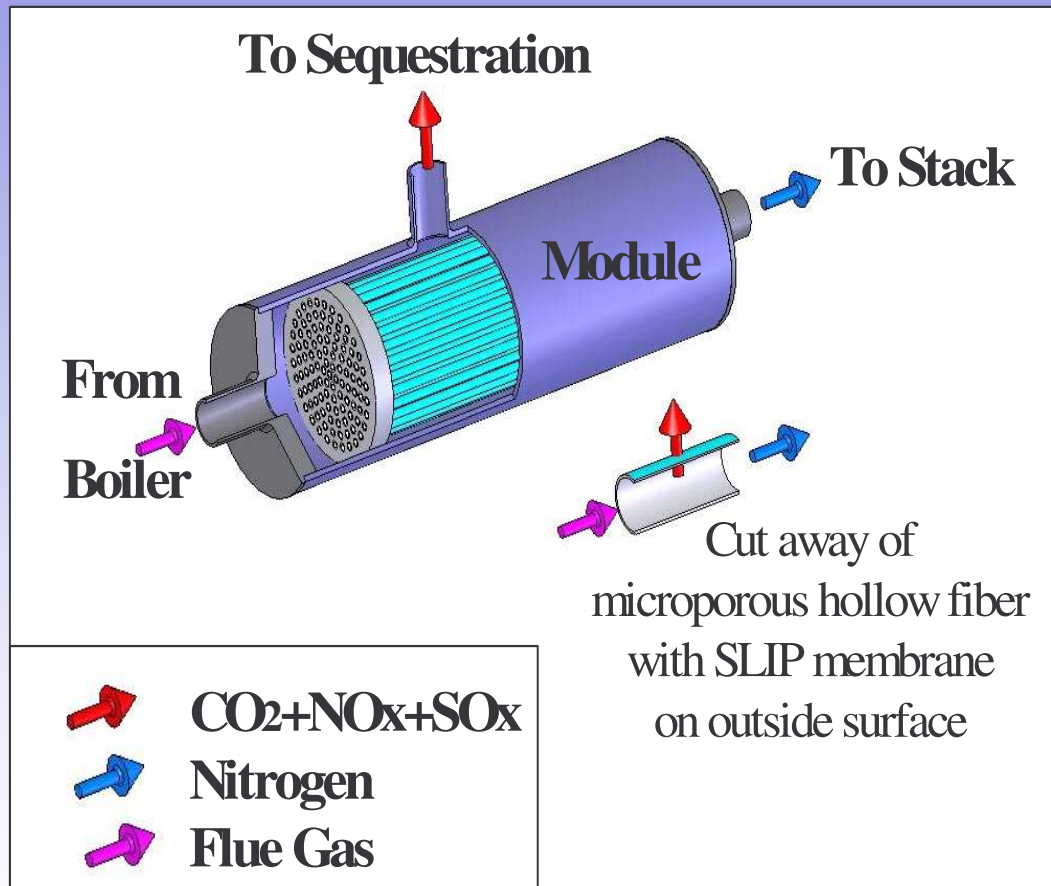
Year 2



*Deploy and Test
Skid at Power Plant*

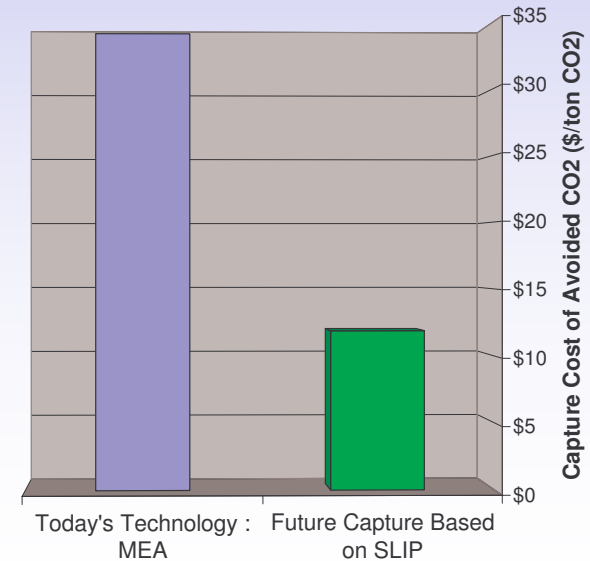
Year 3

Advanced Gas Separation Membranes Lower Cost of Carbon Capture



Schematic of working
membrane module

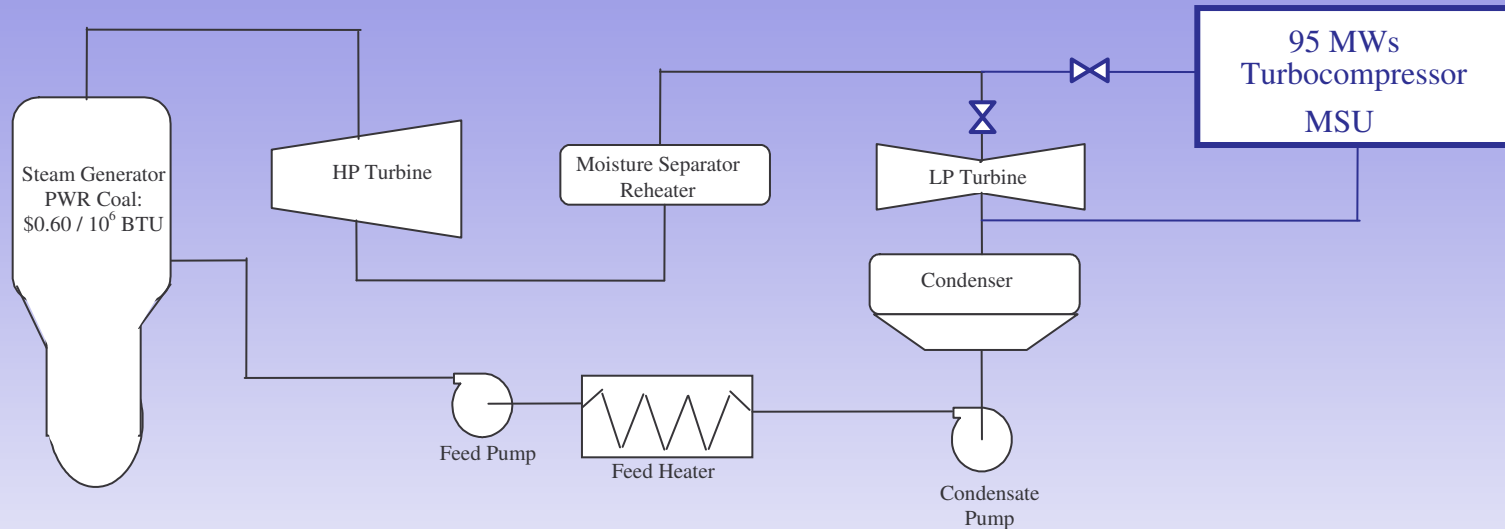
Target Cost expected to be 65% lower than conventional amine-based technologies



SLIP Post Combustion Capture Economics

- Basis 500 MW pulverized coal power plant
- Base plant on-site power cost : \$35/MWH
- Capture plant cost w/ NO_x/SO_x Cr.: \$42.50/MWH
- Tons CO₂ emission / MWH w/o capture: 0.813
- Tons CO₂ emission / MWH w/ capture: 0.182
- Capture cost \$/ ton CO₂ avoided: \$11.90
- Storage compression cost \$/ ton CO₂ avoided: \$3.70
- Combined cost \$/ ton CO₂ avoided: \$15.60

Flexible Pairing of Post Combustion Membrane With a Steam Cycle



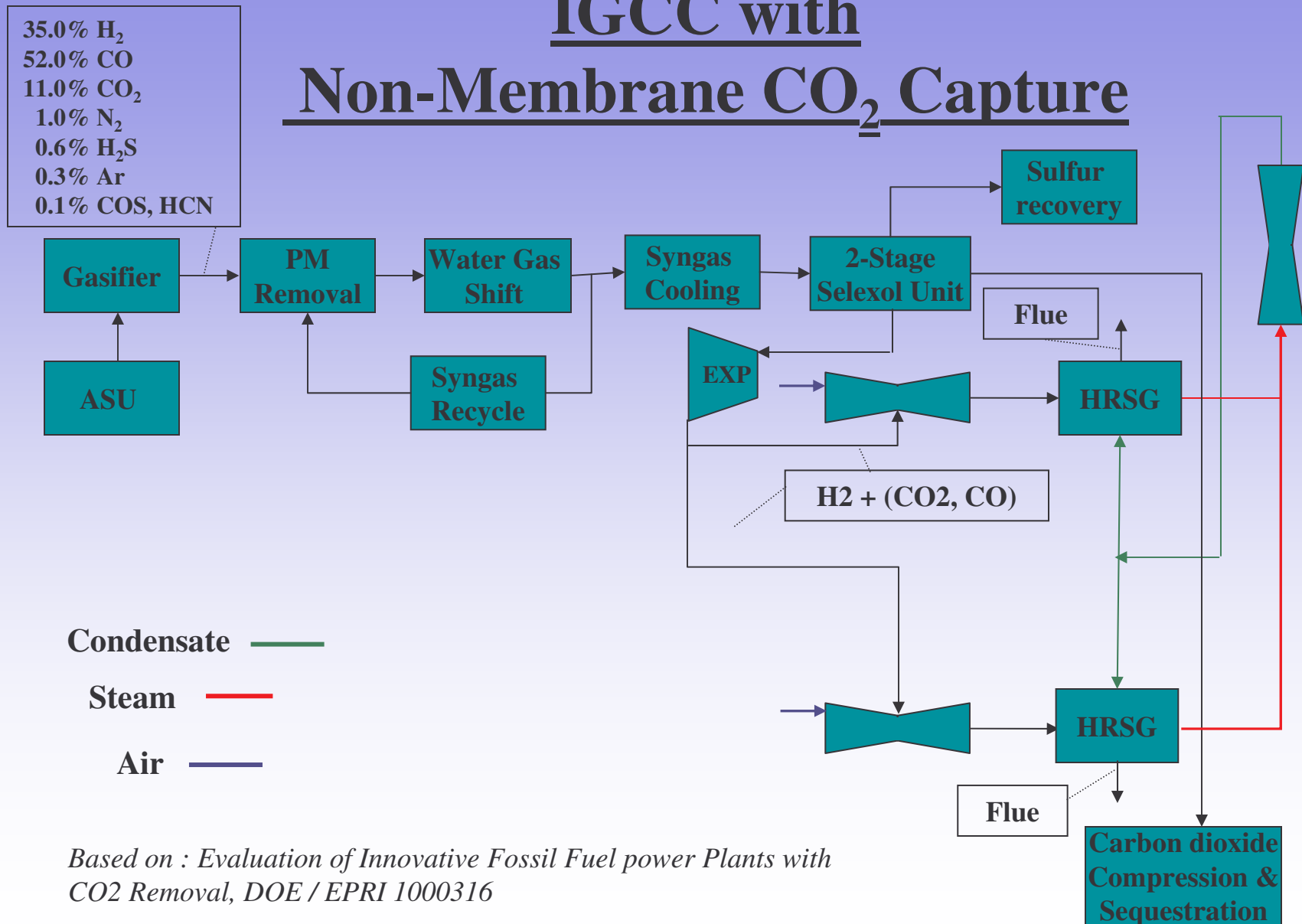
Features and Benefits:

- **The non-chemical MSU can be shutdown and restarted quickly.**
- **Quick shutdown and restart of the MSU enables a coal power plant to supply base and peak load power.**
- **Fuel would be Powder River (PWR) coal at \$0.95/ Million BTU instead of a separate peak load power plant fueled by gas or oil at \$7.00/ Million BTU.**

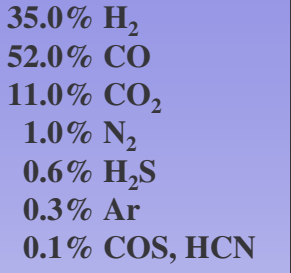
Pre Combustion Carbon Capture

- Coal gasification syngas
- Membrane selectively permeates H_2 & retains CO & CO_2
- Economics driven by permeability & selectivity in the membrane for H_2 over CO & CO_2
- Higher permeability lowers membrane capital
- Higher selectivity lowers capture power

IGCC with Non-Membrane CO₂ Capture



IGCC With



Condensate

Steam

Air —

Pre Combustion Membrane Features

- Removes WGS reactor unit
- Removes Selexol CO₂ Unit
- Adds an MSU
- Increases ASU capacity

Pre Combustion Membrane Benefits

- MSU carbon capture system reduces capital and thermal demand increasing IGCC efficiency
- MSU carbon capture system eliminates the possibility of H₂ loss in the CO₂ solvent stripper
- MSU carbon capture system cost goal is <\$10.00 /ton CO₂ avoided

Pre Combustion Membrane Vs. WGS & Solvent Absorption Considerations

- Added O₂ cost is \$2.55/ton CO₂ captured
- Saved 5% H₂ loss is \$2.50/ton CO₂ captured
- Added challenge to design CO fueled gas turbine in addition to a H₂ fueled gas turbine

Summary

- Advanced and current membranes have applications for both Post and Pre Combustion respectively
- Post combustion methods utilizing advanced SLIP based membranes show promise for CO₂ capture in existing Pulverized Coal facilities
- Pre combustion methods utilizing existing membranes are economic today
- Economics of pre combustion will improve utilizing SLIP membranes